



## Two year experience in the operation of the first community photovoltaic system in Cuba

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### Abstract

Although the photovoltaic technologies have been introduced in Cuba for more than 10 years, the long-term stable operation is still an aspiration. With the setting in operation of the first community photovoltaic electrification system, it was possible to carry out a systematic study of the factors that determine the loss of quality of the operative state of the systems by means of the detection and classification of failures detected in periodic technical inspections. The data analyzed on the basis of the medium frequency of failures allowed discovering problems of technology and its social adoption. This analysis leads to the design of a system for maintenance and repair that guarantees the sustainability of the project. The technical characteristics of the equipment that adapts better to the real conditions of exploitation in the country were determined as well. © 1999 Elsevier Science Ltd. All rights reserved.

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## 1. Introduction

As part of the Cuban national program of rural electrification a total of 217 DC Photovoltaic Systems with power of up to 500 Wp have been installed in Guama municipality. Among these stands out the first community PV system in operation since November 1995. It is composed of 118 stand-alone facilities. However, like in other experiences [1–3], the long-term stable operation of the facilities is still an aspiration: failures of different types affect the operative state gradually degrading it, which increase the operation cost due to substitutions and repairs ahead of time. In previous works this problem has been approached from a technological point of view [4,5] and also from an integrated perspective [6] which has enabled the establishment of a series of rules that should be adopted when taking into account the regional and local specific characteristics. Therefore the establishment of a system to insure the quality facilities that reduce the operation cost to normal limits on operating facilities requires a deep study on the failures that affect the long-term stability.

## 2. Studies carried out

For the proposed study, a system sample was selected:

- A group of isolated facilities of the Community PV System ‘La Magdalena’ (Group I).
- 19 stand-alone systems installed in social objectives (10 medical posts, 7 social circle and 2 schools) of the same town (Group II). This group was selected as a reference one because it is homologated with relationship to the components with more failure frequency.

The program of technical inspections embraced a three year period covering two aspects:

- Operative state of the systems.
- Classification of the detected failures.

Taking into account the degree of execution of the service for which they were designed four categories were given to the operative state:

- **Excellent**: no affectation to the service.
- **Well**: affectations until 50%.
- **Regular**: more than 50% affectations.
- **Bad**: null service.

According to the system component where they are presented, the failures were classified into five groups:

- **A**: Photovoltaic array.
- **B**: Battery.

- C: Battery controller.
- D: DC lamps.
- E: Installation.

### 3. Results of the study

It can be appreciated in Fig. 1 the temporary evolution of the operative state in the Group I systems is incomplete, because the growing tendency of the categories **B** and **R** is incompatible with the apparent stabilization of category **W**. With the help of group II data the evolution toward the inversion of the qualitative scale could be understood.

The data on the classified failures which was gathered in the inspections are shown in Fig. 2 as the temporary evolution of the medium failure frequency  $\omega(t)$  [7]:

$$\omega(t) = \frac{n_f}{N \times \Delta t} (\text{day}^{-1})$$

where  $N$  is the number of inspected components,  $n_f$  is the number of detected failures, and  $\Delta t$  is the time between an inspection and the previous one.

### 4. Analysis of the results

B1 shows an oscillating behavior as a result of the application of corrective measures that are not yet systematically put into practice.

B2 begins to grow lineally after the first inspection as a result of the operation time and the lack of distilled water in the area.

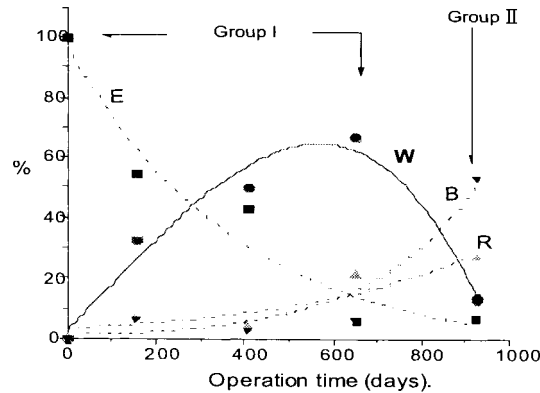


Fig. 1. Temporary evolution of the operative state of the systems.

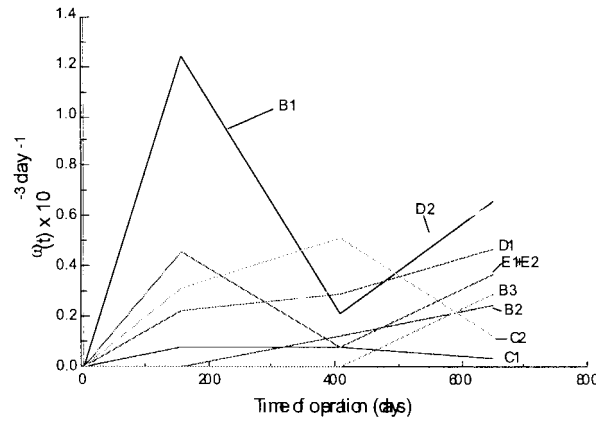


Fig. 2. Evolution of the classified failures in the inspections of the Group I. Legend: B1, weak cells in the battery; B2, electrolyte low level; B3, electrolyte pollution; C1, switching levels changed in the battery controller; C2, wrong functions of the controller; D1, failure of the DC ballast in the lamp; D2, Failure of the fluorescent tube; E1, weak borne in the battery installation; E2, other problems in the installation.

D1 shows an exponentially growing tendency in  $\omega(t)$ . The empiric adjustment leads to:

$$\omega(t) = \exp[-8.3850 - 2.8448 \times 10^{-4}t + 2.135t^2]$$

the work probability without failure is calculated [7]:

$$p(t) = 1 - \int_{156}^{652} \omega(t) dt = 0.8469$$

This now means that in a population of 652 ballast 11 get out of order every month. The temporary evolution and the physical composition of the failure suggests an accumulative parametric failure, which becomes catastrophic when surpassing the tolerance limits of the parameter for the right operation.

D2 shows an exponentially growing tendency with a slope higher than the previous one. From the first inspection on  $\omega(t)$  is going to behave as follows:

$$\omega(t) = \exp[-9.0972 + 0.0002t + 8.26 \times 10^{-7}t^2]$$

And then:

$$p(t) = 0.8321$$

(i.e. 14 tubes deteriorate every month). However, the orientation calculus settles down a working probability without failure for the lamps:

$$97.4 < p(t) < 99.7\%$$

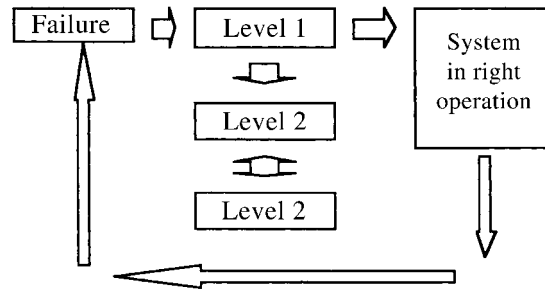


Fig. 3. Organization outline of the attention system to failures.

This probability is higher than the one really obtained. The physic analysis of the failure leads to the establishment of a direct relationship with D1. On the other hand, the ballast design guarantees a very low crest factor and very small DC component [8] in the output. Therefore we attribute this premature failure [9] to constructive problems in the ballast.

With reference to the required level of attention, data reveals that the total number of failures can be grouped at three levels: with an incidence up to 7% the first one, between 50 and 62% the second, and between 33 and 50% the third. The system of attention can be designed according to the outline in Fig. 3.

The system when normally operating generates failures, which are taken care of by the own user (Level 1). If the failures are solved, the system passes again to normal operation; otherwise the local technician (Level 2) will substitute or repair the faulty components. The faulty components will go to the repair shop (Level 3) and then return to Level 2. The modular character of the systems support the whole outline, their dynamism, and economy.

The study carried out indicates that the material resources that guarantee the readiness of components depend on the quality, the quantity installed, and their designs. For the system developed in 'La Magdalena' the material resources were calculated on the basis of the occurrence failures charts by categories and in per cent of the total number of components.

The battery failures can diminish with the use of temperature compensated controllers and the implementation of boost charge, following the current international tendency.

## 5. Conclusions

The failures, which mainly determine the unfavorable evolution of the DC systems for PV rural electrification in the studied sample are located in the fluorescent lamps with free oscillator ballast and in lead-acid flooded batteries. In the first ones, probably due to constructive problems and in the second because of

insufficient training of the users, lack of distilled water in the towns, and the technological non-implementation of the boost charge and the temperature compensation in the battery controller.

Starting from the study carried out a group of measures can be established which should increase the degree of social adoption of the technology and assure its long-term stable operation at minimum cost. Both are essential factors for the project sustainability under the development conditions of the actual Cuban society. The data demonstrates that such measures should include: the acceptability requirements of the equipment which is installed, the organization of a local infrastructure of maintenance, repair, spare parts supply, and a set of regulations for the exploitation and adapted conservation of the equipment.

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